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# COMPRESSIVE STRENGTH TESTING OF TOUGHSKIN THIN SPRAY-ON LINER

Qiuqiu Qiao, Jan Nemcik, Ian Porter and Ernest Baafi

*Abstract:* Thin spray-on liners (TSLs) have been attracting more and more attention as an alternative to the steel mesh in underground roadway support. In order to investigate and compare the compressive strength of glass fibre reinforced ToughSkin TSL developed at the University of Wollongong, a compression test was developed using the cube samples of 40 mm in size. The effect of a small amount of glass fibre in the polymer matrix was tested. The test results indicate that the compressive strength and the material stiffness of the cube samples increased with the increase of glass fibre. All of samples exhibited ductile stress strain curve as they had a yield point and a fracture point. The ductile ToughSkin yield characteristics are very important as sudden brittle failure is considered unsafe for mining practices.

## INTRODUCTION

Thin spray-on liner (TSL) is a relative new form of rock support in underground coal mines. ToughSkin which is a glass fibre reinforced polymeric material liner has been under development as part of the ACARP project at the University of Wollongong. The polymeric ToughSkin has the properties that satisfy the specified safety requirements for the underground coal mining industry. Experiments indicate that ToughSkin TSL support is able to provide reinforcement to the substrate immediately when rock movement begins which is desirable for rock reinforcement. ToughSkin is currently investigated as being an effective substitution for the steel mesh which is of a passive nature and does not contribute significantly to roadway skin reinforcement.

Many experimental tests such as tensile, shear, tear, bond in tension and shear, buckling and flexural strength have been conducted at the University of Wollongong laboratory, and the tested results were published (Nemcik *et al.*, 2008; 2009a; 2009b; 2009c; 2011a; 2011b; 2012; Nemcik *et al.*, 2013a; 2013b; Qiao *et al.*, 2014a; 2014b; 2014c; 2014d; 2015; Shan *et al.*, 2014;). This paper reports the experimental results on the compressive strength of ToughSkin. There is no standard testing method to determine the compressive strength of TSL materials therefore cubes 40 mm in size reinforced with various amounts of glass fibre were chosen for testing. The aim of this test is to determine the compressive strength of TSL and attempt to establish a standard testing method for the compression test for TSL materials.

## SAMPLE PREPARATION

### Selection of sample shape and size

It is desirable to perform compression testing of the fibre reinforced ToughSkin material. This has proven difficult as the polymeric material is not viscous enough to evenly distribute the fibre within the large sample. To obtain reliable results, the glass fibre should be evenly distributed within the polymeric material. Due to limited curing time (approximately 10 minutes) it was very difficult to mix large amounts of fibre into the material and almost impossible to prevent air bubbles entering the mixture. It was decided to use the 40 mm steel cube moulds that are commonly used in the industry to test various materials. The cube mould assembly is shown in Figure 1..

The steel mould assembly consisted of 12 small cubical moulds placed on a metal block. The dimensions of the multiple moulds were cubes of 40 mm side. This setup had an extra advantage as multiple samples can be poured at the same time reducing the sample preparation time. The cube has a further advantage that its sides do not need to be machined prior testing as the steel plates make five out of six sides perfectly smooth ready for the compressive test. Being a steel mould, it does not deform or crack during the TSL sample preparation and curing time. In addition, it is easy to grease the mould which makes the process of removing the samples easy.



**Figure 1: Steel mould assembly of 40 mm cubes**

#### **Procedure of toughskin sample preparation**

- a) All contact surfaces of the mould were greased using a thin film of sprayed oil to ensure that samples can be easily removed from the mould.
- b) The polymer components were mixed evenly according to the manufacturer's recommendations using a plastic cup and a wood spatula.
- c) The glass fibre was mixed evenly into the ToughSkin solution while in the plastic cup.
- d) The final polymer mix was poured into the mould ensuring that the glass fibre was evenly distributed.
- e) The previous steps were repeated for all samples within the mould assembly.
- f) The assembly was placed in the oven at 60°C overnight to cure the polymer.
- g) The samples were carefully removed and the sharp surfaces sanded down until smooth and ready for testing (Figure 2).

The chosen mould enabled quick sample preparation for the compression tests however, several problems occurred during the process. The polymer became harder to mix as the glass fibre content increased. It was practically impossible to mix more than 1% of glass fibre into the mould. This amount of fibre is far less than would be normally sprayed in ToughSkin application. The sprayed product would normally consist of more than 30% glass fibre. Other methods must be trialled to achieve much greater fibre percentage for testing and therefore, new methods need to be devised to solve this problem. Typically air bubbles entrapment within the solution occurs when introducing the fibres into the mixture. This problem can be overcome using vibration or a vacuum chamber treatment however, due to the fast curing this approach is also limited.

Three sets of samples with varying glass fibre content were prepared. Three cubes had no glass fibre, three cubes had 0.5% of glass fibre and three samples contained 1% of glass fibre.

#### **Compression test setup**

The compression test was carried out using the Instron hydraulic testing rig. The polymer samples were loaded to failure, while load and deformation were recorded. The Instron testing device is shown in Figure 3 below.



Figure 2: Completed samples



Figure 3: Compression strength – test setup

### Test results

Testing of the first two samples with 1% glass fibre and no fibre showed that the polymer samples gradually failed with violent outbursts of small debris flying at considerable velocities away from the yielding samples. This made the experiments unsafe so the initial tests were terminated prematurely. To solve the problem, a cloth was wrapped around the subsequent samples and testing resumed.

The average compressive strength for the samples without glass fibre reinforcement was 77.7 MPa, for the samples with 0.5% glass fibre reinforcement was 82.1 MPa, and for the samples with 1% glass fibre reinforcement was 86.9 MPa as shown in Table 1. The test results are shown in Figure 4 depicting the stress strain behaviour of the polymer samples during the uniaxial compression tests. All test results are summarised in Table 1 below.

The compressive test results indicate two distinct elastic zones. Within the first 6% of strain the material stiffness is approximately 7.8 GPa after which the strain softening occurs reducing the stiffness to

approximately 1.4 GPa. Small increase of the fibre glass content has slightly increased the overall material stiffness.

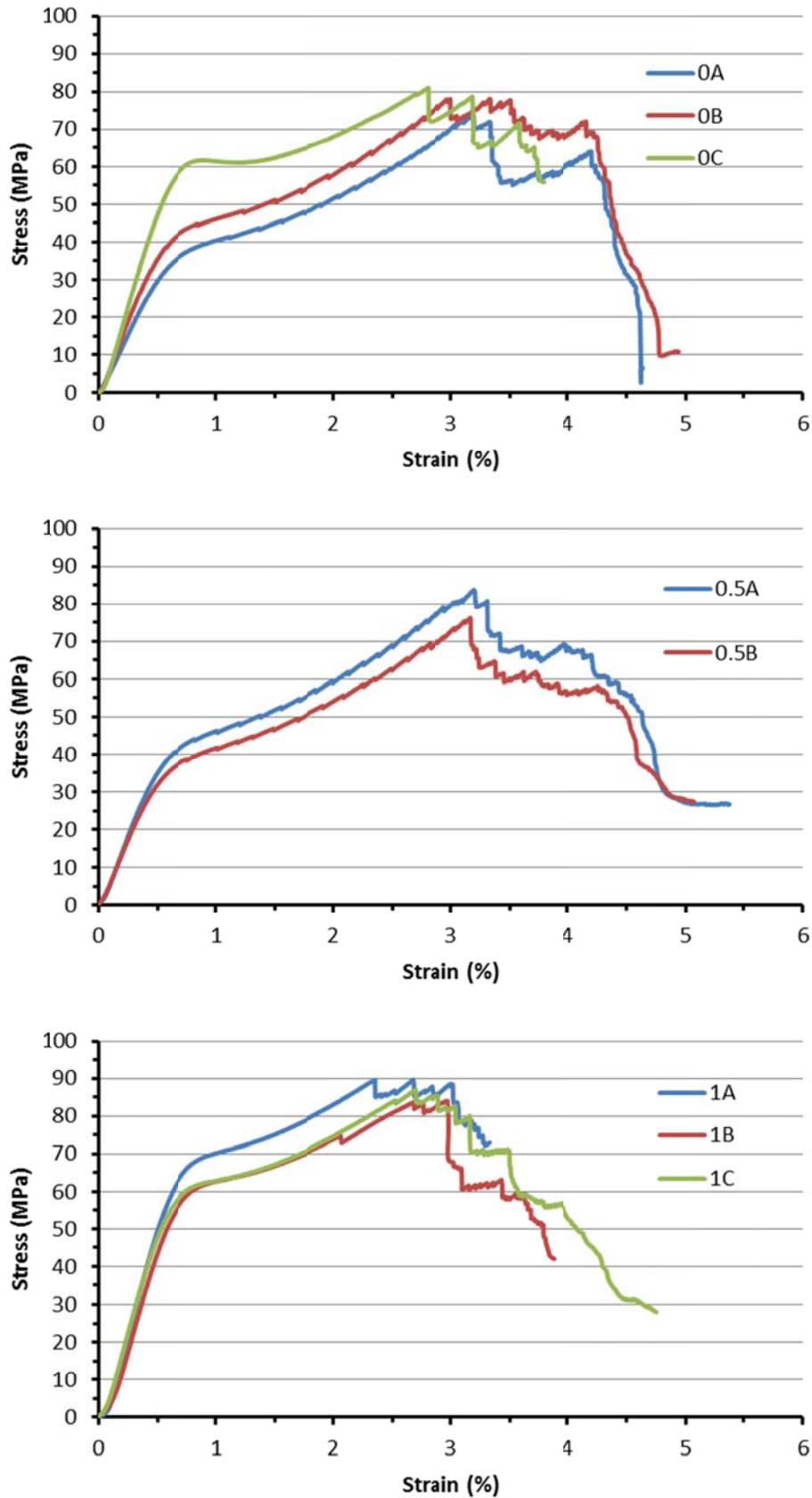


Figure 4: Stress versus strain graphs for all the samples with different glass fibre content

**Table 1: Test results - summary of all ToughSkin samples (40 mm cubes)**

| Glass fibre content | Test Number | Compressive strength | Mean strength |
|---------------------|-------------|----------------------|---------------|
| 0%                  | A           | 73.84                | 77.67         |
|                     | B           | 78.15                |               |
|                     | C           | 81.04                |               |
| 0.5%                | A           | 83.79                | 82.09         |
|                     | B           | 76.21                |               |
|                     | C           | 86.27                |               |
| 1%                  | A           | 89.64                | 86.91         |
|                     | B           | 84.04                |               |
|                     | C           | 87.07                |               |

## DISCUSSIONS

The test results indicate that as expected the averaged compressive strength values were similar as the glass fibre concentration in the reinforced samples was low. Despite the low fibre concentrations the samples with 1% of fibre were on average approximately 11% stronger than the samples with no fibre. This result indicates that the compressive strength of the ToughSkin samples with larger fibre content should dramatically increase the material strength. Further compressive tests of samples with higher glass fibre content are recommended to enable strength determination of the sprayed ToughSkin material. This can be achieved by repetitive spraying of the material components to build up a thick layer of material that can be cut and tested.

The measured strain softening of the material prior to peak load appears to be significant and independent on the glass fibre content. This behaviour can be desirable for material formulations with low glass fibre content as the material provides a significant reinforcement at the initial stage of loading and retains relatively high loads at higher strains. This behaviour is further complimented by high strains during the post failure loading. Higher glass fibre contents within the polymeric material may produce much higher stiffness of the material in compression. Further tests need to be undertaken for formulations with higher fibre to quantify the results.

The stress-strain test data shown in Figure 4 indicate that after the peak strength is exceeded there is a gradual reduction of the load. No abrupt failure of the material was observed until the load reduced significantly. A gradual reduction in post-failure strength reduction is desirable in underground application. It is expected that increase of the glass fibre would further improve the post-failure behaviour with large strains before the total separation of the material occurs. This can be confirmed by testing the sprayed material. Brittle failure characteristics of the ToughSkin would be sudden and unsafe for mining practices.

The violent outbursts of small debris flying at considerable velocities away from the yielding samples need to be studied further to ensure safety. It is envisaged that large amounts of the glass fibre within the loaded material would eliminate such brittle failure mechanism. Further tests are necessary to validate this comment.

The percentage of the glass fibre and the air entrapment within the polymer mixture needs to be researched as they can significantly affect the compressive strength. When spraying the material on the rock surface, the external mixing and the air assist spray stream can produce variable outcomes. The effect of air entrapment together with the fibre content needs to be quantified once the sprayed samples are available.

## CONCLUSIONS

The aim of this study was to develop a suitable method to measure the compressive strength of the glass fibre reinforced TSL material and to provide compressive strength comparison of different TSL products. The method using the steel cube mould was selected as it is practicable and able to withstand the heating of large samples caused by the exothermic reaction during the resin setting period. The test results indicate that the compressive strength of all tested 40 mm cube samples ranged from 78 MPa to 87 MPa. The compressive strength of cube samples increased slightly with the small increase of glass fibre content. The measured sample stiffness also slightly increased with the small glass fibre content.

These results indicate that larger glass fibre contents may produce more dramatic increase in stiffness, compressive strength and the post failure strain.

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